Title	Vehicle in-cabin contactless WiFi human sensing
Authors	Ibrahim, Mohammed;Brown, Kenneth N.
Publication date	2021-07-26
Original Citation	Ibrahim, M. and Brown, K. N. (2021) 'Vehicle in-cabin contactless WiFi human sensing', 2021 18th Annual IEEE International Conference on Sensing, Communication, and Networking (SECON), Rome, Italy, 6-9 July, pp. 1-2. doi: 10.1109/SECON52354.2021.9491580
Type of publication	Conference item
Link to publisher's version	https://secon2021.ieee-secon.org/ - 10.1109/SECON52354.2021.9491580
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Download date	2023-05-07 19:11:04
Item downloaded from	http://hdl.handle.net/10468/11815

Vehicle In-Cabin Contactless WiFi Human Sensing

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***Abstract*—We demonstrate in-cabin WiFi-based sensing in a real vehicle, tracking a passengers breathing rate in real-time.**

***Index Terms*—In-Vehicle Monitoring, In-Cabin, Wireless Sensing, Channel State Information, Contactless, Respiration Sensing.**

I. Introduction

In-cabin sensing has been proposed to support safety in vehicles and in operator-occupied heavy machinery. The aim is to detect and monitor presence, activity, gestures and attention. The most powerful sensing is video-based, but this generates privacy concerns. RF sensing has been proposed as an alternative. It is contactless, it can operate out of line-of-sight, and is less intrusive. Several companies now offer commercial in-cabin RF sensing solutions for smart vehicles [1] [2]. WiFi devices are cheaper and easier to install than other wireless sensing technologies. Additionally, WiFi is expected to replace Bluetooth for in-car interaction, and a wide range of WiFi-based applications is now available in smart cars. WiFi-based in-vehicle sensing was first proposed in 2014 for gesture recognition [3], and has since been applied to many other applications. CSI-based sensing techniques have become increasingly popular in recent years, allowing more applications that were not possible with traditional RSSI-based ones. In WiFi CSI experiments, modified laptops, routers, desktops, and USRPs are typically utilized. The use of the same hardware and recording techniques in-vehicle had restricted research implementation and design, and potentially impaired validity and performance during recording. The majority of previous studies of in-vehicle sensing have relied heavily on external infrastructure outside the vehicle or were conducted in simulation environments or closed labs/garages. Previous work focused on artificial scenarios, and was limited to single occurrences of the activity. For applications such as driver distraction and fatigue detection, this method is not reliable, as time and frequency are critical to the decision-making process.

We propose a new set up, providing continuous data collection and activity recognition. We designed a data collection method that is easy to deploy, can be controlled remotely, requires no interaction from the passengers in vehicle once installed, and is based on COTS devices. The demo will show a passenger's breathing rate being detected in real-time in a real stationary vehicle while the engine is running.

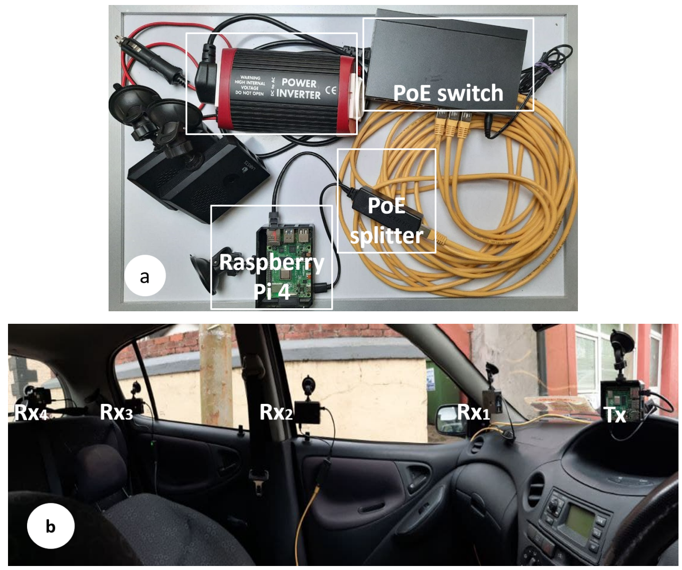

Fig. 1: (a) Demo equipment; (b) Experimental setup.

II. System Overview

Our demonstration uses four Raspberry Pi with Raspberry Pi OS Lite installed, a Power-over-Ethernet (PoE) switch, PoE splitters, and a DC-AC power inverter. Fig. 1 shows an overview of the system. We assume an Internet connection exists inside the vehicle. One transmitting and three receiving nodes were used for communication on channel 36 at 5GHz with 80MHz bandwidth. The communication was configured in injection mode, in which the transmitter controls the number of packets sent. Nexmon CSI Extractor Tool [4] is installed on the receiver nodes to collect CSI from the transmission link. PoE was chosen to provide data and power to each node using a single Ethernet cable. Raspberry Pi nodes through PoE splitters are connected to the PoE switch with CAT5e cables. Power is supplied by an AC-DC inverter connected to the cigarette lighter of the vehicle. In our experiment, a smartphone connected to the switch acts as a source for internet access via Ethernet Tethering.

The placement of transmitters and receivers has been left as an open research question on all previous studies. We use Raspberry Pi cases that are designed with a tripod hole, so it can be mounted just about anywhere using a suction cup on the windshield, rear window, or side windows. Using the embedded antenna on the Raspberry Pi chip for transmission and receiving, we were able to avoid using RF cables, which had been found to significantly affect in-vehicle channel measurements [5].

As soon as the vehicle starts, each Raspberry Pi automatically boots up and sends out an NTP query to set the correct time before start listen. Upon receiving a packet, receivers perform the following operations: 1) decrypt the packet; 2) extract the CSI amplitude measurements; 3) timestamp the CSI data; 4) log the time-stamped amplitude values.

III. EXPERIMENT AND EVALUATION

In smart vehicles, many different respiration sensing technologies are proposed, each with its own advantages and limitations [6]. Breath-monitoring via WiFi is a promising option for daily home use and has been implemented in vehicles. Previous work on In-Vehicle WiFi-based respiration tracking [7] have explored several applications including Driver Fatigue Detection [8], Driver Authentication, Passengers Counting, and Child Detection [9].

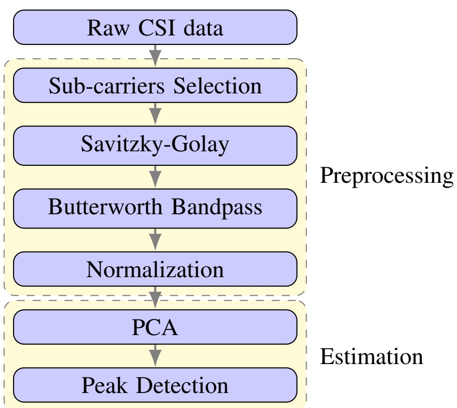

Fig. 2: Overview of the WiFi Signal processing flow

Human breath tracking. Fig. 2. shows the WiFi CSI signal processing flow for Human breath tracking as implemented in our system. From each pair of transmitter-receiver, the CSI is extracted from 256 sub-carriers. Before the data preparation and filtration, the sub-carrier variances are analyzed to identify those sensitive to the breathing activity. A Savitzky-Golay filter is used to smooth CSI data at each sub-carrier by replacing each point with the least-squares polynomial fit of its neighbours, set to a kernel window of one second and a polynomial of 3rd order. In order to filter out the signal component that is caused by human breathing, a 5th order Butterworth band-pass filter was then applied to filter the data between 0.2 and 0.35 Hz corresponding to a normal adult breathing rate. Using Z-score normalization, we suppress changes in the gain offset of each sub-carrier and make them comparable. For dimensionality reduction, we perform Principal Component Analysis (PCA) on the band-pass filtered CSI stream. To accurately identify breathing rate, a peak detection algorithm finds all local maxima and filters fake peaks with interval thresholds based on the maximum possible breathing rate. In Fig. 3, an example of CSI processing is shown, following the same process flow as in Fig. 2.

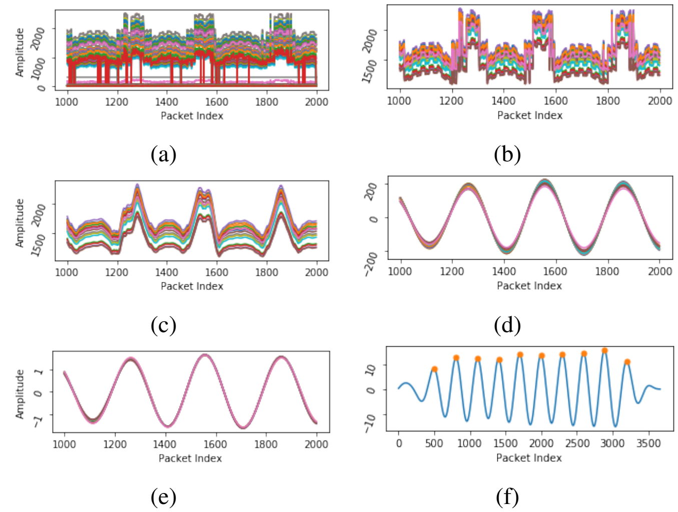

Fig. 3: (a) Raw CSI from Rx_1 (256 sub-carriers); (b) Selected CSI; (c) Savitzky-Golay filterd CSI; (d) Band-pass filtered CSI; (e) Normalized CSI; (f) PCA-filtered CSI (Rx_1, Rx_2, Rx_3) and Peaks Detected.

ACKNOWLEDGMENT

This publication has emanated from research conducted with the financial support of Science Foundation Ireland under Grant number 16/RC/3918 (Confirm SFI Research Centre for Smart Manufacturing) which is co-funded under the European Regional Development Fund.

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